

## PIXEL DEFECT CORRECTION IN A CMOS ACTIVE PIXEL IMAGE SENSOR

### FIELD OF THE INVENTION

The invention relates to the general field of color imaging with particular reference to permanently correcting the handling of bad pixels.

### BACKGROUND OF THE INVENTION

A CMOS image sensor consists of an array of Field Effect transistors, each of which acts as a pixel, together with various support circuits for driving and reading out the signal. A bad pixel is defined as a pixel whose response is noticeably different from the response of the other pixels in the array under dark or uniformly illuminated conditions. Pixel defects can be caused for many reasons including high leakage, circuit defects, dust particles, scratches, color filter nonuniformity, or microlens defects. The two extremes for such defects are: dead pixels, which are always dark, and hot pixels which are always saturated. No matter their origin, bad pixels degrade image quality because even one defective pixel can stand out in an image made up of millions of good pixels.

Color interpolation, sharpening and other software-based image processing

## VISA-56

operations are often used to neutralize the effects of bad pixels but these can actually further degrade image quality by corrupting good pixels that are the neighbors of a bad pixel. Additionally, a bad pixel introduces high frequency components to an image which impacts the compression ratio.

Another method of dealing with defective pixels involves the use of two exposures in succession with a small diagonal shift of the entire sensor of 10 to 20 pixels between the two exposures. The computer then combines the two exposures into a single image which will have very few missing pixels. For further accuracy, this method can be extended to three successive exposures with diagonal shifts of the sensor between each exposure.

Although it is highly desirable to have an image sensor that is entirely defect-free, selecting arrays having only good sensors with not a single bad pixel is not a viable alternative as it would drive down manufacturing yield and significantly increase cost. The present invention teaches how image sensors may be made to be effectively defect-free by detecting, and then correcting for, the bad pixels. An approach of this type carries with it the additional benefit of making arrays, that might otherwise have been rejected after testing, useable.

A routine search of the prior art was performed but no references that teach the

VISA-56

exact processes and structures of the present invention were discovered. Several references of interest were, however, encountered along the way. For example, in US Patent 5,528,043 and U S Patent 5,886,353, Spivey, et al. both describe an imaging system for producing images from electromagnetic radiation such as x-rays. Their system includes a detector comprised of a radiation-absorbing layer sandwiched between an array of CMOS integrated circuits (pixel circuits) and a surface electrode layer transparent to the radiation. Each of the pixel circuits in the array has a charge-collecting electrode. An external voltage applied between the surface electrode layer and the charge collecting electrodes produces an electric field across the thickness of the absorbing layer. pixels and even missing rows or columns are corrected by having the computer assign values to the missing pixels by interpolation between the values of the neighboring pixels.

## SUMMARY OF THE INVENTION

It has been an object of the present invention to provide a method for correcting bad pixels in a CMOS image sensor array.

Another object of the invention has been that said method require only a single

VISA-56

exposure of the image that is being sensed at the time the bad pixels are corrected.

A further object of the invention has been that said method be easy to implement and not significantly impact current manufacturing processes for making said sensors.

These objects have been achieved by a two step method in which the addresses of bad pixels are recorded during sensor testing and stored in an on-chip directory. Then, during sensor readout, each pixel address is checked to determine if it represents that of a bad pixel. If this is determined to be the case, the bad pixel value is replaced by another value. This replacement value can be generated from an average of the nearest-neighbors that are not defective.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of a Bayer pattern color mosaic.

FIG. 2 illustrates how two nearest neighbors may be used to correct a bad pixel.

VISA-56

FIG. 3 illustrates the case when one of the nearest neighbors is itself defective.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

The method of the present invention may be divided into two principal steps. The first step is to record the addresses of bad pixels during sensor testing, both with and without illumination. These addresses are permanently stored on-chip (for example, by means of fusible link technology, anti-fuse technology, or flash memory technology). The second step is implemented during sensor readout. Each pixel address is checked to determine if it represents that of a bad pixel. If this is determined to be the case, the bad pixel value is replaced by another value. This replacement value is generated from an average of the nearest-neighbors that are not defective. All these operations are easily integrated with the CMOS image sensor hardware on the same IC chip.

In a monochromatic sensor, nearest neighbors would also be immediate neighbors but, in a color sensor, the replacement value will necessarily be generated from other pixels that are the same color as the bad pixel. To illustrate the method of the present invention, a color sensor 11 with a Bayer pattern color mosaic -- blue-green, green-red (BG,GR) is shown in FIG. 1. A Bayer pattern is a particular assignment of color patterns in a two dimensional color filter array. A typical example of a unit pattern for a Bayer

## VISA-56

pattern is a 2x2 array in which the upper left cell is blue (B), upper right cell is green (G), lower left cell is green (G), and lower right cell is red (R), hence the (BG, GR) designation. The Bayer pattern is constructed from the repetition of the unit pattern. The pixel defect correction algorithm can be simplified by using only pixels in the same row to generate the replacement value. As each row contains only two colors (in this example), a 5-pixel buffer is sufficient for implementing the correction scheme (see FIG. 2). This points to the bad pixel 20 and its nearest neighbor replacements 21 and 22. If one of the same-color nearest neighbors 31 (see FIG. 3) is also a bad pixel, the replacement value becomes the remaining same-color nearest neighbor 32. If both same-color nearest neighbors are also bad, the bad pixel cannot be corrected (unless a larger buffer is used). Alternatively, if pixel outputs from multiple rows are stored, pixel correction based on two-dimensional calculation can be implemented.

Therefore, this algorithm, implemented on a color sensor with a Bayer mosaic, can correct up to 4 consecutive bad pixels in a row (in this example). The number of bad pixels in a column or diagonal is limited only by the number of bad pixel addresses that can be stored. Once a bad pixel has been identified, a flag can be generated which can then be used in association with specially provided on-chip circuitry, by a companion ASIC, or by the host computer to locate the bad pixel and replace it with a different (corrected) value. An even better estimate could be generated from the values of all the nearest-neighbors, including those in different rows, if the time and space for doing so are available..